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ABSTRACT

High-ability Jamaican students in grades one, three, five, seven, and nine were asked to draw five three-dimensional objects (cuboid, pyramid, cylinder, cone, cube) from memory, and with the object visible; later they were asked to select the best sketch of each solid from among several presented. Drawings and selections were scored for primitiveness on a five-point scale, and scores on the three tasks were compared. The two drawing scores were combined; reliabilities computed were .93 (combined drawing) and .53 (selection). Developmental trends, sex differences, and correlations of these scores with spatial tests, illusion tests, and background variables were examined. (SD)

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DEVELOPMENT AND VALIDATION OF THE SOLID REPRESENTATION TEST IN A CROSS-SECTIONAL SAMPLE OF JAMAICAN STUDENTS

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Work in the scientific and technological professions frequently requires the application of mathematics to the solution of physical space problems. Many problems reduce to plane geometry or trigonometry, but it is often necessary to work in all three dimensions (3D). Then the first step is to draw a diagram which adequately represents the depth dimension, after which it is usually possible to break the problem down into a series of two-dimensional calculations. Especially common is the shape of the cuboid (rectangular prism) which occurs either as a box or as the abstract framework for a rectangular coordinate system. Drawing this and other mathematical solids is therefore a skill which is widely used in industrialized societies.

Although many psychologists and artists have noticed cultural differences in methods of representation (Gombrich, 1960; Stern, 1909; Thouless,1933), few have studied in any details how people without an industrial tradition draw 3D objects. Hudson (1962) collected drawings of a cow, an elephant, and a car made by illiterate South African mineworkers and found that most of them were "developed," that is, showing front and side views in one diagram; Deregowski (1970) found that Zambian uneducated women actually preferred such drawings. In another study, Deregowski (1969) gave Zambian domestic servants and primary school children a 3D wire model of part of the framework of a cube (the edges of the front and back faces and one of the edges joining them) and found a clear tendency to draw the faces side by side instead of overlapping.

These results, even when read in conjunction with the much wider literature on cross-cultural differences in perception, do not necessarily imply that educated people in developing countries are unable to represent 3D objects using conventional perspective methods, but they do suggest that they might have some difficulties. Indeed, Hudson (1960) found that university lecturers had some problems over the interpretation of diagrams of 3D scenes, and Mitchelmore (1973) found that a sample of Jamaican secondary

school mathematics teachers were significantly poorer at 3D drawing than a comparison group of U.S. student teachers of mathematics. It is possible that students of many spatially-loaded disciplines in the developing countries could be seriously handicapped as they strive to master the same subject matter as their North American and European colleagues.

A survey was undertaken to study the ability of Jamaican students to represent 3D mathematical relations on paper (Mitchelmore, 1974), intending to obtain comparative data from industrialized countries later. No tests were available to measure this ability, so they had to be developed. The present paper reports the development and validation of a test of the ability to draw simple mathematical solids, called the Solid Representation Test (SRT), and presents some preliminary results.

Background

The development of children's spontaneous representation of 3D scenes has been studied by observing single children (Eng, 1954) and by classifying collected drawings (Munro et al., 1942). Although there are differences in detail, four stages are generally reported (Lowenfeld & Brittain, 1966; Luquet, 1929):

1. Objects float in space, not properly related to each other or to any base line.
2. Objects shown in correct topological relation to each other but without any depth depiction, often showing mixed viewpoints (Lascaux perspective).
3. Attempts to show depth by multiple base lines, overlapping, and even size differences, from a single viewpoint.
4. Correct representation, objects related to a base plane, horizon in background.

Eisner (1967) developed a detailed 14-category system for classifying drawings according to the presence of base/horizon lines and how objects were related to them and each other.

Drawings of single objects must be classified differently, but it seems likely that development will follow the same general pattern. The only researchers to produce concrete evidence are Kerr (1936) and Lewis (1962, 1963). Lewis had classes of children sketch a transparent sphere, a cubical house, and a diorama. Her stages for the house, following Arnheim (1954) and Kerr, showed the following sequence: (1) an isolated square face; (2) mixed viewpoints, no depth; (3) mixed viewpoints, some depth; (4) depth represented by drawing sides parallel; and (5) perspective drawing. Petitclerc (1972) presented sketches of a pyramid and a cube said to be typical of various age levels, but gave no data to justify her scale.

Method

Pilot testing It was necessary to decide whether to use group or individual testing, solid or transparent models, and everyday or abstract models. Pilot testing indicated that group testing and the use of transparent models led to intolerable ambiguities of interpretation and that everday objects had distracting features irrelevant to depth perception. The test was therefore designed to be administered individually using opaque, abstract models in a fixed orientation with the subject viewing them from a fixed distance and direction. Also, since representing depth on a sphere seemed to be more an artistic than a mathematical problem, this shape was not included.

Apparatus The apparatus eventually devised for the Solid Representation Test is shown in top view in Fig. 1. In the box, there are painted models of (from left to right) a blue cuboid measuring 10 cm x 5 cm x 2½ cm, a red cylinder of height 5 cm and diameter 5 cm, a green square pyramid of height 5 cm and base side 5 cm, a yellow cube of side 5 cm, and an orange cone of height 5 cm and base diameter 5 cm. Colors are used to allow easy identification

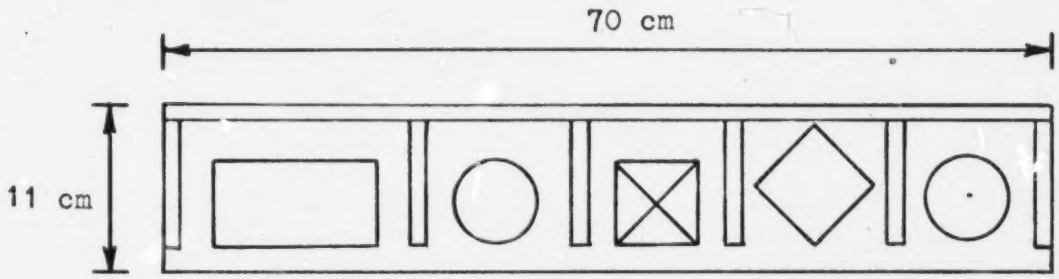


Fig. 1 Top view of SRT apparatus

without using the names of the solids. Each model is in a compartment large enough to allow an unobstructed view, and each compartment has a lid so that the models can be displayed one at a time. The numbers 1 to 5 are painted on the outside of each lid in the same color as the model inside; the remainder of the apparatus is pointed white inside and out.

The apparatus is used with a chin rest attached to an extension arm which fits under the box and includes a wedge to tilt the box. Three chin rests have been constructed for different sizes of children; the wedges compensate for the height of the rest so that all subjects view the central pyramid from a distance of about 50 cm at an angle of elevation of about 30°. The subject's-eye-view is illustrated in Fig. 2.

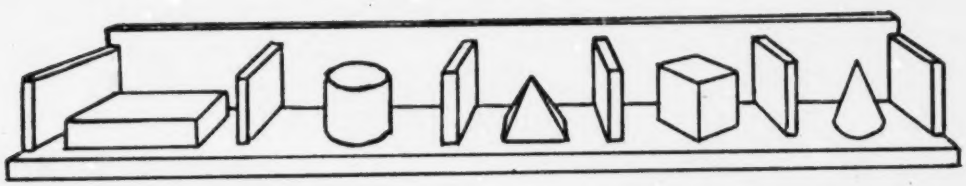


Fig. 2 Subject's-eye-view of SRT apparatus (lids not shown)

Procedure For the present study, the following three-condition procedure was adopted. In Condition 1, the subject was shown each solid for a short time (about 1 s) and then drew it from memory. In Condition 2, each solid was displayed for as long as the subject wished while he drew it. In both these conditions, subjects were instructed to draw each block exactly as they saw it and to make their drawings "look solid, like a photograph." In Condition 3, the subject was shown six drawings of each solid alongside the model and asked which he thought was the best drawing of the block.

This procedure allowed an empirical validation of the scoring system, since Condition 2 should not produce more primitive drawings than Condition 1, nor should there be more advanced representations drawn in Condition 2 than selected in Condition 3. The alternatives for Condition 3 were selected from those drawn in the pilot testing, chosen to represent stages in a preliminary classification; they were drawn in black ink in a random order on 20 cm x 13 cm file cards which were then covered with transparent plastic for protection.

Subjects Eighty high-ability students from Grades 1, 3, 5, 7 and 9 in Kingston, Jamaica public schools were tested during January to March 1974. All subjects were attending an academic high school or likely to do so in the future. Subjects in Grades 7 and 9 were selected at random from representative classes of representative (academic) high schools, whilst those from Grades 1, 3 and 5 were selected at random from the top classes of the largest elementary schools with the best records of passes to high school. To control for school differences, two schools were assigned to each sex at each grade level; four students were tested in each school. Students were in the regular age range for each grade; their mean ages for each grade were 7.2, 9.6, 11.2, 12.6, and 14.4 yr respectively, boys' and girls' means being little different.

Scoring Before sorting the 160 drawings of each solid, each drawing was labelled with a random number to avoid scoring bias.

The cube and cuboid were sorted first. Most drawings fell into a fairly clearly defined sequence which did not, however, match that of Lewis (1963) quoted on page 3. Few drawings combined mixed viewpoints with depth depiction (her stage 3) and no subject drew any solid using converging lines to represent parallel edges. There were two stages between her stages 2 and 4; one showing the first breakaway from the exclusive use of rectangles to represent the faces, and the second showing better attempts which were not quite correct. Boundaries between stages were clarified by ordering the borderline cases and imposing an arbitrary cut-off point. A few schematic drawings, either showing the solid correctly from a different viewpoint or showing the hidden edges correctly, were noted and assigned to the nearly-correct category.

Drawings of the pyramid were sorted next. Five stages similar to those for the cube and cuboid were identified, although the division into stages was not quite so clear as for the rectangular solids. Boundaries between stages were clarified in the same way as before.

The cylinder produced the widest variety of drawings and was the most difficult to score. Drawings which showed both end faces were clearly more primitive than those showing only the top face; drawings with a top face shown by a circle were more primitive than those in which it was shown by an ellipse; and drawings with the bottom edge shown by a straight line were more primitive than those in which it was shown by a curve; but what was the relative importance of these factors? Was a drawing with both faces shown by ellipses more or less primitive than one in which the top face was shown by a circle and the bottom edge by a straight line?

To obtain an empirical answer to this problem, drawings of the cylinder were ordered using the scores on the other drawings (cube, cuboid and pyramid) made by the same student in the same condition. Drawings showing the ten most common types of error (including the most primitive type of a simple outline) and the obviously correct

drawings were examined first; then for each of these eleven categories, the mean score was found for drawings of the other solids. These means showed the correct order for most of the paired comparisons mentioned above, but also showed that some apparent improvements in drawing were not very significant. The mean scores for the drawings of the other solids were therefore used to group and order the drawings of the cylinder; this gave the general outline of the scoring system, and the remaining drawings were fitted in where they were felt to be appropriate.

Attempts to score the cone produced serious anomalies, including many cases of students who made perfect drawings of the cone but the most primitive drawings of the other solids. It was eventually realized that a general outline of the cone (one of the most primitive representations) was indistinguishable from the correct representation. Drawings of the cone were therefore eliminated from further consideration.

The classification adopted for the cuboid, cylinder, pyramid, and cube showed the following stages:

0. An outline of the solid or one face viewed orthogonally.

1. Several faces shown but not in a correct relation to each other, often both visible and invisible faces shown, usually no depth depiction.

2. Only visible faces shown, in correct relation to each other but with poor depth depiction.

3. All appropriate faces distorted in an attempt to show depth, but not correctly.

4. Solid drawn correctly by representing parallel edges of the solid with parallel or slightly converging lines.

The similarity to stages for representing 3D scenes (see page 2) may be noticed. Typical drawings at each stage are illustrated in Fig. 3. The detailed scoring system, showing all the most common errors, is available from the author.

Condition 3 was scored using the stages to which each of the alternatives was assigned by the above procedure. It was found that several of the alternatives were rarely chosen or drawn, but there was still a good coverage of the five stages for each solid.

Validation

Order of conditions Cross-tabulations of responses under the three conditions are given in Tables 1 and 2. Table 1 shows that Conditions 1 and 2 usually (in two-thirds of the cases) produced drawings in the same stage and that Condition 1 rarely (less than 10%) gave more advanced drawings than Condition 2. Table 3 shows that Condition 3 was usually (again in two-thirds of the cases) easier than Condition 2 and that Condition 2 very rarely (less than 5%) gave more advanced drawings than were selected in Condition 3.

Developmental patterns Frequencies of responses by grade are shown for Condition 1 in Table 3. There was a fairly clear improvement in drawings from grade to grade for each solid, although only for the cylinder was there a good number of correct representations drawn in this condition even by Grade 9 students. Most of the Stage 0 drawings of the cube and cuboid in Grade 5 were made by girls.

Consistency Scores for the four solids were added to give an SRT total for each condition. Because Conditions 1 and 2 gave such similar results, these totals were added to given an SRT drawing score. Condition 3 was retained as an SRT selection score. The reliabilities of these scores (Cronbach alphas) were 0.96 and 0.53 respectively.

Summary The low proportion of deviations from the expected order of the three conditions, an adequate developmental pattern of improvement from grade to grade, and the high reliability of the SRT drawing score constitute satisfactory validation of the SRT administration and scoring procedures. (The low reliability of

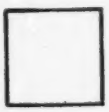
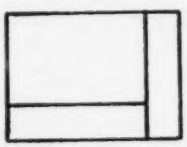
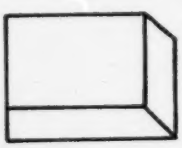
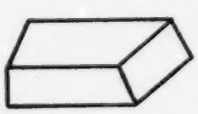
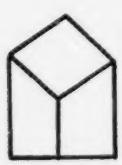
Stage	Solid			
	Cuboid	Cylinder	Pyramid	Cube
0				
1				
2				
3				
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Fig. 1 Typical drawings at each stage of solid representation

Table 1

Frequencies of scores on SRT items
(Condition 1 versus Condition 2)

Score under Condition 1	Score under Condition 2				
	0	1	2	3	4
Cuboid					
0	27	7	2	1	1
1		8	2		
2			5	5	3
3		1	2	8	6
4				1	1
Cylinder					
0	17	2			
1		14		1	
2	1	1	3	4	1
3	1			12	6
4				2	15
Pyramid					
0	18	4	1	2	
1	1	9	5	2	2
2	1	4	5	9	
3			2	11	4
4					0
Cube					
0	25	2	1	1	
1		4			
2			10	5	
3	1		4	17	3
4			1	2	4

Table 2

Frequencies of scores on SRT items
(Condition 2 versus Condition 3)

Score under Condition 2	Score under Condition 3				
	0	1	2	3	4
Cuboid					
0	4	1	5		17
1	1		1	1	12
2					12
3		1			14
4			1		10
Cylinder					
0	1	2		3	13
1		6			11
2				1	2
3				1	18
4		2			20
Pyramid					
0	10	1	3	2	4
1	3	2	5	6	1
2			5	5	3
3			2	9	13
4					6
Cube					
0	4	2	1		19
1			2	1	3
2	1			2	13
3				1	24
4				1	6

Table 3

SRT response frequencies by grade (Condition 1)

Score	Grade				
	1	3	5	7	9
			Cuboid		
0	14	10	9	4	1
1	2	5	2	1	0
2		1	3	2	7
3			2	8	7
4				1	1
			Cylinder		
0	10	4	4	1	
1	5	3	4	3	
2	1	5	3	0	1
3		4	3	7	5
4			2	5	10
			Pyramid		
0	12	6	5	2	
1	3	4	4	5	3
2	1	5	4	6	3
3		1	3	3	10
4					0
			Cube		
0	12	7	9	1	
1	3	1	0	0	
2	1	5	1	5	3
3		3	5	7	10
4			1	3	3

the selection score was probably due to a poor choice of alternatives but it could also be the result of the narrow spread of scores.) It should be admitted that the scoring of the cylinder was designed to maximize the reliability of the total score, and that drawings were not scored independently. Cross-validation is therefore necessary before the reliability of the scale for general application can be estimated. It is certainly high enough to allow a closer look at the results obtained from the present sample.

Results

Representational schemata The closeness of scores under Conditions 1 and 2 support the notion that each subject possessed schemata for representing certain types of solid and only modified them slightly to fit any given model (Gombrich, 1960). Although subjects frequently glanced from model to drawing in Condition 2, in most cases this caused only minor modifications to the drawing; indeed, several cases were noted where students simply drew over a line they had erased. Only for the pyramid did seeing the model make much difference (see Table 1); this was also the most difficult solid to draw or recognize, as shown in Table 2. Perhaps this shape is less common and there is less opportunity to develop a schema for it.

Sex differences Mean SRT scores by sex and grade for both drawing and selection are illustrated in Fig. 4. The linear trend was significant for both scores ($P < 0.001$) but the sex difference was significant ($P < 0.001$) only for the drawing score. The grade-sex interaction was also significant for drawing, and post hoc tests using Tukey's procedure showed that the sex difference was only significant in Grades 3 and 5 ($P < 0.02$).

This sex difference is all the more significant in Jamaica because more girls than boys attend school (the ratio is about 2:1) and they do better on the mainly verbal public examination taken in

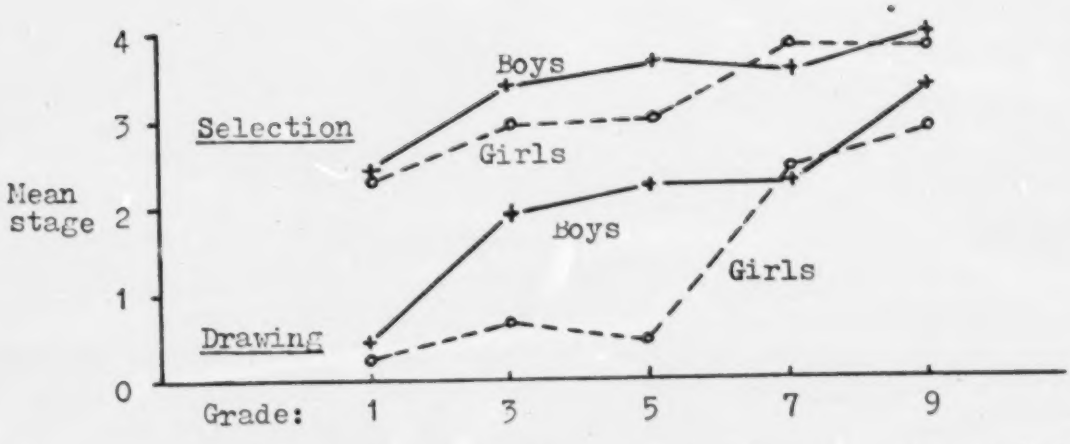

Fig. 4 Mean SRT scores by condition, sex and grade

Grades 5 and 6 for selection to high school (Manley, 1963). The same pattern as in Fig. 4 was observed in other spatial tests given to the same sample (see below) and a check showed that the difference at Grade 5 was not due solely to the schools selected. Why the difference vanished in Grades 7 and 9 is not known; a clear sex difference in favor of boys was found in a companion survey of Grade 9 students using group tests of 3D drawing and spatial ability (Mitchelmore, 1974).

Correlations with other variables All students were also given the following tests: a Hidden Figures Test in which the simple shape was displayed alongside the pattern in which it was embedded; Ord's Design Construction Test (1970), a 2-dimensional adaptation of the WISC Block Designs; tests of drawing the vertical (telegraph poles alongside a winding road) and horizontal (water level in tilted bottles); the geometric illusion measures designed by Herskovits et al. (1969), omitting the Poggendorf illusion; and a test of hand and eye dominance. Data were collected from students on number of siblings, the presence or absence of a father or father-substitute

during childhood, and social class (obtained using Miller's (1967) rating of occupations), and subjects' skin color was rated subjectively on a 5-point scale.

Correlations of the SRT scores with the above variables and age are shown in Table 4. Higher scores on the illusion measures indicate greater susceptibility; the direction of measurement of the background variables is shown in the table by giving the meaning of the higher scores on each variable.

Both SRT scores had moderately high correlations with the other spatial test scores, with the exception of the vertical representation test. The correlations within sexes were slightly lower for boys and slightly higher for girls. There was no suggestion of a separate factor for drawing or of separate factors for 2-dimensional and 3-dimensional tests. The correlations are, of course, inflated by the wide age range, and when age is partialled out, the correlations drop to about 0.40 -- except for girls' drawing, where they merely fall to the level in the overall sample.

The only correlations of the SRT scores with the illusion measures to reach significance were those for the first horizontal-vertical illusion, in which the better drawers were least susceptible. One could draw conclusions from this result were the correlations with the other illusion measures not so small! The only correlations with the background variables measured to reach significance were those for number of siblings and for social class, where they confirmed the usual result that children from higher social-class homes do better on intellectual tests. The correlations were again slightly higher (numerically) for girls than boys, which suggests that girls are more susceptible to social influences; this could be one reason why they appear not to develop their spatial ability as quickly as boys. Presence or absence of a father figure seemed to have no effect on spatial ability, neither did variations in skin pigmentation.

Table 4

Correlations of SRT drawing and selection scores with scores on spatial tests, geometrical illusion measures, and background variables*

Variable	Higher score	SRT	
		Drawing	Selection
Spatial tests			
Hidden Figures		0.81	0.66
Design Construction		0.84	0.70
Vertical Representation		0.59	0.40
Horizontal Representation		0.80	0.69
Geometric illusions			
Muller-Lyer		-0.18	-0.19
Horizontal-Vertical (⊥)		-0.39	-0.29
Horizontal-Vertical (⅂)		-0.03	-0.03
Sander Parallelogram		0.11	-0.01
Perspective illusion		-0.08	-0.04
Background variables			
Age	Older	0.74	0.63
Hand dominance	Right	-0.18	-0.05
Eye dominance	Right	0.18	-0.00
Number of siblings	Greater	-0.19	-0.26
Father in childhood	Absent	-0.16	-0.10
Social class	Lower	-0.13	-0.31
Skin color	Darker	0.01	-0.08

*N = 80; $P(|r| \geq 0.22) = 0.05$, $P(|r| \geq 0.28) = 0.01$.

Conclusion

The development of a Solid Representation Test (SRT) using four common mathematical solids and three conditions of representation has been described. Evidence was found of the test's validity when used with a cross-sectional sample of Jamaican high-ability students aged 7-14, and the results were used to investigate methods of representation, sex differences, and the relation of representational ability to other aspects of spatial ability and to various background variables.

No cross-cultural data has yet been obtained. The indications from pilot testing (very unreliable because of changes in procedures) are that Jamaican high school students may be superior in spatial ability to average North American students; however, Grade 9 high school students scored much higher than students in the non-selective secondary schools in Jamaica in the companion survey (Mitchelmore, 1974) so the average Jamaican student may be considerably poorer at representing solids than the students sampled in the present study. Vernon's (1965) comparative analysis based on a small sample of Jamaican 11-year old boys also suggests that this might be the case.

The stages in drawing the rectangular solids which were shown in the present sample differed substantially from those adduced by Lewis (1962, 1963). Further research is required to determine whether the differences are merely due to differences in administration and models used, or whether they reflect fundamental cross-cultural differences in the development of representational ability.

It is hoped to collect data on the SRT from U.S. students in December and from other samples of Jamaican subjects at a later date. It would be valuable to have data from high-ability students in countries which are less developed than Jamaica, where the problems may be more serious. It is also important to find how much it is possible to improve solid representation by instruction (Dawson, 1967).

Acknowledgements

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